# Modified method for extraction of watershed boundary with digital elevation modeling

WANG Dian-zhong[1, 2], HAO Zhan-qing[1], XIONG Zai-ping[1]

[1] *Institute of Applied Ecology Chinese Academy of Sciences, Shenyang 110016, P. R. China*

[2] *Graduate School of Chinese Academy of Sciences, Beijing 100039, P. R. China*

**Abstract**: Boundary extraction of watershed is an important step in forest landscape research. The boundary of the upriver watershed of the Hunhe River in the sub-alpine Qingyuan County of eastern Liaoning Province, China was extracted by digital elevation modeling (DEM) data in ArcInfo8.1. Remote sensing image of the corresponding region was applied to help modify its copy according to Enhanced Thematic Mapper (ETM) image's profuse geomorphological structure information. Both the DEM-dependent boundary and modified copy were overlapped with county map and drainage network map to visually check the effects of result. Overlap of county map suggested a nice extraction of the boundary line since the two layers matched precisely, which indicated the DEM-dependent boundary by program was effective and precise. Further upload of drainage network showed discrepancies between the boundary and the drainage network. Altogether, there were three sections of the extraction result that needed to correct. Compared with this extraction boundary, the modified boundary had a better match to the drainage network as well as to the county map. Comprehensive analysis demonstrated that the program extraction has generally fine precision in position and excels the digitized result by hand. The errors of the DEM-dependant extraction are due to the fact that it is difficult for program to recognize sections of complex landform especially altered by human activities, but these errors are discernable and adjustable because the spatial resolution of ETM image is less than that of DEM. This study result proved that application of remote sensing information could help obtain better result when DEM method is used in extraction of watershed boundary.

**Key words:** Forested watershed; Boundary extraction; Digital elevation modeling (DEM); Enhanced thematic mapper (ETM)

**CLC number:** S715 **Document code:** A **Article ID**: 1007-662X(2004)04-0283-04

## Introduction

With the prompt application of modern methods and technologies in forest landscape research, watershed boundary determination as an indispensable step has progressed to use cell-based digital elevation modeling (DEM) as major data source (Niu 2003). DEM data is a kind of grid input to modeling the characteristics of the land surface. Recently, it has been widely used in map, engineering, geology, landscape architecture, road design, flood control, agriculture and planning (Fan & Zhan 2002). The applications of GIS and DEM advanced the collection, transportation, processing and query of hydrological information (ESRI 2001a, 2001b; Shu & Zhang 2002). DEM data consists of two aspects: one is demonstrative information that includes corner coordinates, size of a grid, number of rows, etc., and the other is elevation information that includes the elevation value of each grid. The coordinates of non-corner grids are not stored but calculated from their positions in the matrix and geometric characteristics of the grids. DEM can be used to calculate and analyze the hydrologic characteristics such as storage volume and submerge area when applied to a natural watershed (Li & Hao 2003).

Compared with manual methods, extracting watershed boundary with DEM is a popular method with better precision and efficiency. Effective and efficient ways should be found to solve the problem of imprecise boundary, because an imprecise boundary can alter the area of a watershed even potential forest features (Jiang *et al.* 2002; Hao *et al.* 2004). However, the issue of how to deal with the error generated in the extracted result attracted much endeavor just for improvement of DEM data (Gabrecht & Martz 1999).

Actually, other source of information may be complementary to solve the problem. Enhanced Thematic Mapper (ETM) imagery obtained from Earth Resource Satellite---Landsat-7 has two advantages: one is that it has seven multi-spectral bands, which could provide abundant spectral information to land cover interpretation, and its multi-spectral resolution is 30 m that can meet the precision demand of macro and mediate mapping, thus it can be applied in resource survey and data formation at that level (Xin *et al.* 2003); the other is that ETM imagery adds a panchromatic band, which could provide a resolution of 15 m, thus its effect is better than that of former TM imagery. As a reliable data resource, it can be applied to auditing and management of forest resource. On the basis of such

**Foundation item**: This work was supported by Knowledge Innovation Program, Chinese Academy of Sciences (No. KZCX2-SW-320-3 & KZCX3-SW-425).

**Biography**: WANG Dian-zhong (1979- ), male, postgraduate student of Institute of Applied Ecology Chinese Academy of Sciences, Shenyang 110016, P. R. China. E-mail: wangdianjong@hotmail.com

**Received date**: 2004-09-20

**Responsible editor**: Song Funan

information, this study checked the practical effect and efficiency of ETM landform information for extracting DEM-dependent watershed boundary in the forested area.

## Methods

The study site is located in the upriver watershed of the Hunhe River in the sub-alpine Qingyuan County of eastern Liaoning Province, with a highest elevation of 1 069 m. The elevation of 75% the total area is less than 556 m. The watershed is considered as agro-forestry complex for its abundant fluvial terrace and forest resource (See Wang *et al.* 2004 for details).

1:250 000 DEM data was used to extract the boundary of watershed and the process was composed of three steps. The first step is to fill the depression in DEM. Depression refers to a cell whose elevation value was lower than that of any of its neighbor cells. This phenomenon occurs when the breadth of valley is less than the grid size and the low value of valley decreases the average value of the cell. Since depression usually occurs in upper stream, it is necessary to fill the depression before determining the flow direction. The second step is to determine the direction of flow from every cell in the grid. This is done with the FLOWDIRECTION function. This function takes a grid surface as input and generates a grid output that shows the direction of flow out of each cell. There are eight valid output directions, relating to the eight adjacent cells into which flow could travel. Former elevation values of each cell is substituted by one number among 1, 2, 4, 8, 16, 32, 64, 128 for potential flow direction of east, southeast, south, southwest, west, northwest, north, and northeast. Thus a new digital grid with flow direction is recorded, which is called as flow direction grid. The last step is 'flow accumulation', which calculated accumulating flow as the accumulated weight of all cells flowing into each downslope cell in the output grid. If no value was assigned to the grid, a value of one was applied to each cell, and the value of cells in the output grid would be the number of cells that flowed into each cell.

All the commands were completed in ARC/GIS workstation environment and the ensuing boundary map was obtained.

The principal component analysis was transformed to the corresponding ETM image of the watershed. After that a combination of the first two principal components together with the panchromatic band were chosen to create a new imagery layer. The layer contained most spectral and spatial information of the former ETM image and effectively avoided the former information redundancy. When this image layer was displayed in a scale of 1:100 000, all the natural catchments were visible and mountain ridges were also discriminable. Thereby the extracted boundary from DEM was copied and uploaded upon the image layer. The area inside the boundary occupied one sixth of the total image in center. In ArcMap environment, the overlapping condition of the two layers was visually inspected to find out the disagreement and modify the edge of the boundary layer, i.e. changing the location of the points in the boundary line, according to the image display around the boundary.

## Results and discussion

The results of initial and modified watershed boundary are shown in red in Figs.1, 2 and 3. The area of the new region was only 86.9% of the former because we excluded some parts that showed disorder in ArcMap modification (Fig.3).

Naturally, the drainage network should be included in natural watershed boundary. Moreover, the study region in this research was located inside the county. Thus, the precision of extraction was analyzed by overlap method according to the spatial relationship mentioned above. The maps of drainage network and Qingyuan County were uploaded on the two boundaries and shown in blue and green, respectively (Fig.1 and Fig.2).

After the upload of county map on the extraction result, boundaries of the two vector layers had a nice match underside and upside. In fact, regime boundaries were usually set according to landform. As the extracted result matched the county boundary, it indicated that the dependent extraction result of DEM by program was effective and precise. Further upload of drainage network showed discrepancies between the boundary and the drainage network. There were obvious blanks with little relationship to drainage in the nearside and the upside. What's more, there was a drainage branch went out of the boundary in the upside. These three discrepancies indicated three errors in the automatic extraction result.

Compared with Fig. 1, the modified result in Fig. 2 showed a close relationship and full enclosure of the drainage network. This phenomenon demonstrated that the modified boundary was superior to the initial one in spatial relationship.

Knowledge of the DEM and the study region led us to find out two aspects of the reason. Firstly, the average elevation of study region is no more than 500 m and the geomorphologic characteristics in many places have been altered by human activities. Such complex landform hampered proper boundary detection of program. Furthermore, the nearside was the outlet of the drainage network with a lower average elevation, which was even harder for the program to correctly detect the boundary. The errors generated by program could all attribute to these reasons. Secondly, a DEM was a raster representation of a continuous surface. The accuracy of the data was determined primarily by the resolution (distance between sample points). Other factors affecting accuracy were data type (integer or floating point) and the actual sampling of the surface when creating the original DEM. Thus a DEM could not avoid data intervention and incorrect interpolation

(Gabrecht & Martz 1999), and then create some false characteristics (Li & Zhu 2000). DEM could be improved by program to some extent (Weibel & Heller 1990; Mao & Su 1993), however, errors in DEM data debased the quality of extraction result. With the help of remote sensed data, it is more practical to improve the boundary from landform information.

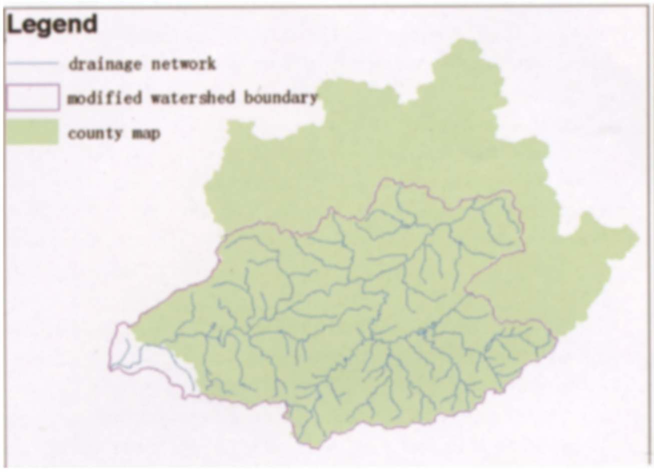


**Fig. 1 Initial DEM-dependent boundary of Hunhe River watershed**

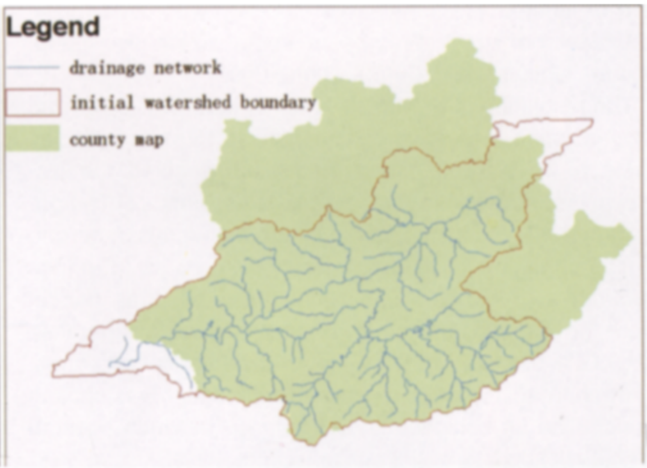


**Fig. 2 Modified DEM-dependent boundary of Hunhe River watershed**

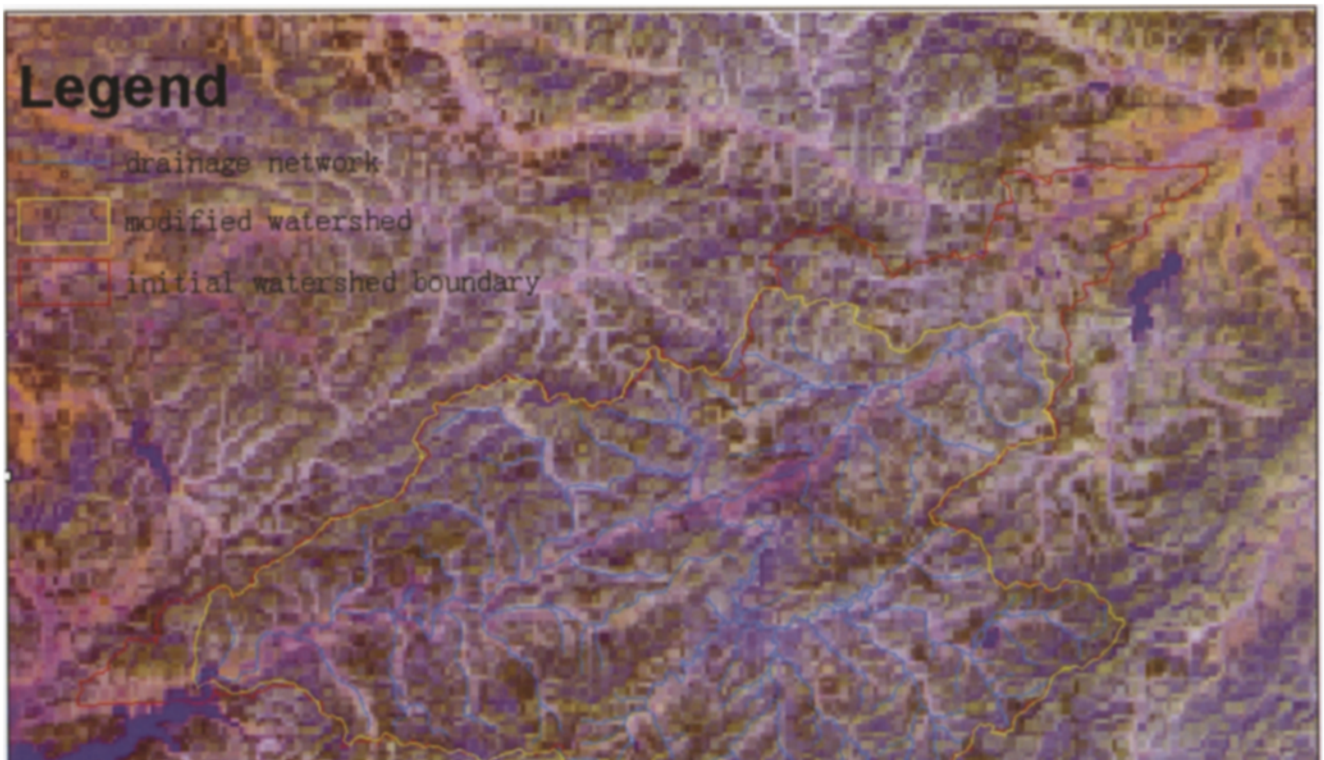


**Fig. 3 Comparison of watershed boundary of Hunhe River on ETM**

Unlike drainage network and county map, which could reflect the sketch of boundary information but showed deficiency in necessary landform information to plot the watershed boundary, remote sensed imagery recorded electromagnetic characteristics of the Earth surface, information of landform included. ETM imagery was used for its abundance of spectral represent shape, size, tune, shade, texture, situation, etc. (Zhu & Zhang 2002).

The resolution of ETM multi-spectral band was 30 m and the resolution of panchromatic band was 15 m. In a display scale of 1: 100 000, these resolutions enabled the discrepancy to be visible. Transformation of principal component analysis enabled spectral information focused on one or two components as much as possible so as to reduce information redundancy between multi-spectral bands. Here the first two principal components account separately for 93.4% and 4.6% information of the total seven bands. Then the panchromatic band of ETM imagery was chosen to combine on consideration of balance between spectral and resolution.

## Conclusions

In this research, a comparison between an initial watershed boundary extracted from DEM and a copy interactively modified was conducted according to ETM imagery. By a comprehensive analysis, It is concluded that the program extraction has generally fine precision in position and excels the digitized result by hand. Yet the errors of the DEM-dependant extraction are due to the fact that it is difficult for program to recognize sections of complex landform especially altered by human activities. These errors are discernable and adjustable. This study result proved that application of remote sensing information could help obtain better result of boundary extraction of watershed when DEM method is used in extraction.

## Acknowledgements

We are grateful to Dr. Anand N. Singh for remarks on an earlier version of the manuscript.

## References

ESRI Inc. 2001a. ArcGIS 8-Using ArcMap, Redland, CA

ESRI Inc. 2001b. ArcGIS 8-Editing ArcMap, Redland, CA

Fan Hong, Zhan Xiaoguo. 2002. ARC/INFO application and development technique (Revised) [M]. Wuhan: Wuhan University Press. p1 (in Chinese)

Gabrecht, J., Martz, L.W. 1999. Digital elevation model issues in water resources modeling [C]. In: Proceedings of the 19th ESRI international user conference. San Diego, California, p254–257.

Hao Zhanqing, Yu Deyong, Lin Fan, Xiong Zaiping, Ye Ji. 2004. Forest resources variation along with the main rivers in typical forest region of Changbai Mountain [J]. Journal of Forestry Research, **15**(2): 101–106.

Jiang Mingxi, Deng Hongbing, Cai Qinghua. 2002. Distribution pattern of rare plants along riparian zone in Shennongjia area [J]. Journal of Forestry Research, **13**(1): 25–27.

Li Li, Hao Zhenchun. 2003. The automated extraction of catchment properties from digital elevation models [J]. Advances in Earth Science, **18**(2): 251–256.

Li Zhilin, Zhu Qing. 2000. Digital Elevation Models [M]. Wuhan: Mapping Science and Technology University Press, p147–150

Mao Kebiao, Su Yuyang.1993. DEM data form and compress coding [J]. Remote Sensing Information, (3): 17–19.

Niu Yuguo. 2003. Modern hydrology and spatial data collecting technique [J]. Journal of Hydrology, **23**(5): 13–15.

Shu Zhenwen, Zhang Daqing. 2001. ArcView GIS application in catchment characteristic analysis [J]. Yangtze River, **32**(9): 41–42. (in Chinese)

Wang Dianzhong, Hao Zhanqing, Pei Tiefan. 2004. The characteristics of hydrology in Hunhe River basin [J]. Journal of Liaoning Forestry Vocation-Technical College, **1**(1): 22–24. (in Chinese)

Weibel, R., Heller, M. 1990. A framework for digital terrain modeling [C]. In: Proceedings of the fourth international symposium on spatial data handling[C]. Zurich, p1219–229.

Xin Haiqiang, Wen Hui, Zhang Yu. 2003. The applications of ERDAS software in the works of forest resource classification [J]. Science of Surveying and Mapping, **28**(2): 39–41.

Zhu Shulong, Zhang Zhanqui. 2002. Remote sensing and image analysis [M]. Beijing: Science Press, p166–167 (in Chinese)